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The Cost Structure of the Japanese Railway Industry: The Economies of Scale and Scope and the Regional Gap of the Japan Railway after the Privatization

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Abstract:
It is said that the privatization of the Japanese National Railway is a success since the management, productivity, and service have improved. However, as expected, the gap of both management and productivity tends to widen between the larger main-island JRs and the smaller three-island JRs. This paper will estimate the cost structure of the six JRs after the privatization. The main points we will make are as follows: first, the economies of scale exist in both the incumbent railway service and the Shinkansen service; second, there is no conclusive evidence to show that the economies of scope exist between them; third, the cost gap between the main-island JRs and the three-island JRs is large; and fourth, the cost gaps within them are also large.

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Introduction

More than ten years have passed since the Japanese National Railway (JNR) was privatized and broken up. The privatization is in general evaluated as a success because the management, productivity, and service have improved following the birth of the Japan Railway (JR) group. However, a problem accompanying the privatization is the regional gap between the larger JRs operating on the main-island of Japan and the smaller JRs operating on three smaller islands. The railway industry has been considered to be one in which the economies of scale obviously exist. It is, therefore, a matter of concern that the large difference in the scale and density of market leads to the cost gap between the main-island JRs and the three-island JRs. Furthermore, the cost gap may be expanded further if the economies of scope exist, because only the main-island JRs are at present operating 'Shinkansen'.

The purposes of this paper are, first, to estimate the cost structure of the six passenger JRs, second, to perform the test of whether the economies of scale and scope exist or not, and, third, to compare the long-term marginal costs of the incumbent railway service and the Shinkansen service[1]. The main points we will make are as follows.

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[1] Several studies have been made to test the economies of scope in the railway industry. For example, Kim (1987) dealt with the American railway industry while Preston (1996) studied the British railway industry. They found that the economies of scope did not exist between the passenger transportation service and the freight service. The originality of this paper lies in the fact that the economies of scope between the two passenger transportation services, the incumbent railway service and the Shinkansen service, will be tested. Tauchen, Fravel, and Gilbert (1983), Harmatuck (1991), Calburn and Talley (1992), Keeler and Formby (1994), for example, are also informative concerning other transportation services.

First, the economies of scale exist in both the incumbent railway service and the Shinkansen service. Second, on the other hand, there is no conclusive evidence to show that the economies of scope exist between them. Third, as expected, the cost gap between the main-island JRs and the three-island JRs is large. Fourth, furthermore, the cost gaps within the main-island JRs and the three-island JRs are also large. The above results will provide an empirical foundation for the policy discussion in the Japanese railway industry, concerning such issues as the complete privatization of the main-island JRs, the subsidy mechanism for the three-island JRs, or the project to construct further Shinkansen railways.

The paper consists of the following six sections. Section 2 briefly surveys the privatization and liberalization of the Japanese railway industry. Section 3 explains the method of a cost estimation and represents the result, while Section 4 carries out the test of the economies of scale and scope. Section 5 analyzes the different costs in each area, and Section 6 draws a conclusion.

An overview of the privatization of the Japanese National Railway

It will be helpful to survey the privatization of the Japanese National Railway before moving on to the main subject. The explanation of this section owes much to Mizutani and Nakamura (2000) and Takeuchi (2000)[2].

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[2] Also see Fukui (1992), Fukui, et al., (1994), Mizutani (1997), Mizutani and Nakamura (1996, 1997), Takeuchi, Imahashi, and Yamauchi (1997) for further details.

The Japanese railway service was inaugurated in 1872 and was basically nationalized in 1906. After the end of World War II, a public corporation called the Japanese National Railway (JNR) was established in 1949 and started to supply the affordable and available service in the public interest. It is in 1964 that two remarkable occurrences happened: the first is that JNR started the Shinkansen service, or bullet train service; the second is that JNR began incurring the operational deficits for the first time. The financial difficulties of JNR continued: the accumulated deficit finally reached 15.4 trillion yen while the long-term liabilities became 25.5 trillion yen in 1986 just before the privatization. This is because of the very characteristic of public corporation as well as the intensified competition with automobiles and airplanes: fares could not be raised without approval by the Diet and the revision was always delayed[3].

On 1 April 1987, JNR was privatized and divided into six regional passenger railway companies, which are now called the Japan Railway (JR) group. Three larger companies (JR East, JR Central, and JR West) are operating on the main-island of Japan whereas three smaller companies (JR Hokkaido, JR Shikoku, and JR Kyushu) are operating on three smaller islands (Hokkaido, Shikoku, and Kyushu). The Shinkansen service is operated only by the main-island JRs[4]. Figure 1 displays the operating areas of the six passenger JRs while Table 1 depicts the average outputs of the incumbent

[3] Furthermore, we have to point out that other reason was the consciousness of 'Oyakata Hinomaru (Rising Sun as Patron)' of JNR, which means that the government (whose symbol is rising sun) would lastly take care of the company whatever the deficit would be.

[4] The infrastructure was at first hold by the Shinkansen Holding Corporation by the vertical separation between the infrastructure and the operation of Shinkansen. However, the assets were bought by the main-island JRs, and the Shinkansen Holding Corporation was dissolved in 1991.

railway service and the Shinkansen service since the privatization, which are represented by 'passenger-km'. At the same time, one freight company (JR Freight) and the JNR Settlement Corporation were established: JR Freight uses the other six JRs' track and pays usage-fees to them; the JNR Settlement Corporation was set up in order to supervise the handling of liabilities and redundant employees.

<Figure 1>

<Table 1>

At present, the Japanese privatization of JNR is regarded as a success. First, the JR group is now in the black and also operating other businesses, though JNR was prohibited from operating other businesses. Second, productivity has improved drastically, the largest factor in which is thought to be the increase in labor productivity. Third, service qualities such as frequency, travel time, speed and so on, have also improved. On the other hand, some problems of privatization have been pointed out. To begin with, the long-term debt has not significantly decreased, and it reached 27.6 trillion yen in 1996[5]. Nevertheless, the construction plan for further Shinkansen railways is still proposed to serve even low-demand areas such as Hokkaido, Tohoku, Hokuriku, and Kyushu, in part because politicians want the Shinkansen service for their constituencies[6]. Next, and more importantly for this paper, the regional gap of the

[5] At first, most of long-term debt had been the responsibility of the JNR Settlement Corporation, but it was taken over by general account and the JNR Settlement Corporation was dissolved in 1998.

[6] In many cases, unprofitable incumbent railway services are abolished instead of the construction of Shinkansen, or a quasi-public sector, such as a joint venture of local governments and private companies, is established to take over the business.

Japanese passenger railway service has seemed to widen. It was truly expected at the time of privatization that the main-island JRs would have advantages and the three-island JRs would be suffering from the managerial problems because their sizes and population densities were quite different. A lump-sum subsidy scheme by the Management Stability Fund was established to solve the problem of regional gap. The three-island JRs have been subsidized by the interest revenue of the Fund, but the amount of subsidy tends to decrease because of Japan's low interest rate policy in the 1990s[7].

The estimation of cost function

This section will explain the estimation model of cost function. JR East, JR Central, and, JR West are operating Shinkansen, whereas JR Hokkaido, JR Shikoku, and JR Kyushu are not. Accordingly, we will estimate them, separately assuming two-output model for the main-island JRs and one-output model for the three-island JRs[8].

The estimation of the two-output model of the main-island JRs

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[7] Originally, there used to be no fare differences within the JR group because it imposed a uniform tariff policy. However, due to the decrease in interest revenue from the Fund, only the three-island JRs decided to increase fares by 6-7% in 1996.

[8] The reason for the separate estimation is that the three-island JRs do not run the Shinkansen service but translog cost function does not admit zero value. One possible method is to adopt the generalized translog cost function that carries out Box-Cox transformation. Box-Cox transformation defines output as $Y_i = (Y_i^{\theta} - 1)/\theta$, which becomes linear in the case of θ=1 and logarithmic in the case of θ=0. At first, we tried to perform the Box-Cox transformation with the pooled data of the six JRs. However, we abandoned this approach because the value of θ did not converge and the model was not proper in this point.

This section will explain the estimation model of the main-island JRs. We assume here a cost function that consists of three inputs of labor force, material, and capital and two outputs of incumbent railway and Shinkansen as follows:

$$C = C(L, M, K, Y_1, Y_2), \qquad (1)$$

given L=labor, M= material, K=capital,

Y_1=the incumbent railway service, and Y_2=the Shinkansen service.

Furthermore, we suppose the cost function to be a translog cost function, which is known as a type of flexible cost function.

$$\begin{aligned}\ln C = \alpha_0 + \sum_{i=L,M,K}\alpha_i \ln P_i + \frac{1}{2}\sum_{i=L,M,K}\sum_{j=L,M,K}\beta_{ij}\ln P_i \ln P_j + \sum_{k=1,2}\gamma_k \ln Y_k \\ + \frac{1}{2}\sum_{k=1,2}\sum_{l=1,2}\delta_{kl}\ln Y_k \ln Y_l + \sum_{i=L,M,K}\sum_{k=1,2}\rho_{ik}\ln P_i \ln Y_k + \sigma_2 D \ln Y_2\end{aligned} \qquad (2)$$

Three inputs prices are defined as follows[9]:

P_L: the labor price = the real personnel expenses / the number of employees at the end of the fiscal year,

P_M: the material price = the real non-personnel expenses / the number of vehicle-km,

P_K: the capital price = the price index of the capital goods×(the interest rate of the government guaranteed bonds + the rate of depreciation),

given the rate of depreciation = the depreciation expenses / the equipment expenses at the beginning of the fiscal year.

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[9] See Monthly Price Index Report by Bank of Japan about the price index of the capital goods and Monthly Economic Statistics Report by Bank of Japan about the interest rate of the government guaranteed bonds.

Also two outputs are defined as follows:

Y_1: the incumbent railway service (passenger-km),

Y_2: the Shinkansen service (passenger-km).

Since Shinkansen of JR Central connects the three metropolises of Tokyo, Nagoya and Osaka, the scale of market is extremely large. Accordingly, we adopt the dummy variable (D=1) for the output of Shinkansen of JR Central. Furthermore, we assume the following constraints of linear homogeneity with regard to input prices in advance:

$$\sum_{i=L,M,K} \alpha_i = 1, \sum_{j=L,M,K} \beta_{ij} = \sum_{j=L,M,K} \rho_{jk} = 0. \tag{3}$$

At the same time, we assume the following symmetry of second-order partial derivatives with regard to input prices:

$$\beta_{ij} = \beta_{ji}. \tag{4}$$

From Shepherd's lemma, the share equations of inputs (i=L,M,K) are obtained as follows:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial C}{\partial P_i}\frac{P_i}{C} = \frac{P_i X_i}{C} = \alpha_i + \sum_{j=L,M,K} \beta_{ij} \ln P_j + \sum_{k=1,2} \rho_k \ln Y_k . \tag{5}$$

The total cost that is the explained variable is the sum of the real personnel expenses, the real material cost, and the real capital cost. The capital cost is defined as the product of the capital stock and the capital price, and the capital stock is defined as follows:

the capital stock = (1- the rate of depreciation) × the capital stock at the previous term + the real gross investment,

given the real gross investment = the amount of annual change of the fixed assets + the depreciation expenses.

We can now estimate the simultaneous equations of the translog cost function, with the constraints of the linear homogeneity and the second-order symmetry, and the share equations of labor and material by the maximum likelihood (ML) method[10].

The estimation of the one-output model of the three-island JRs

This section will explain the estimation model of the three-island JRs. We assume here a cost function that consists of three inputs of labor force, material, and capital and one output of the incumbent railway service as follows:

$$C= C(L, M, K, Y_1). \quad (6)$$

given L=labor, M= material, K=capital,

and Y_1= the incumbent railway service.

The cost function to be estimated is given as follows:

$$\begin{aligned} \ln C = \alpha_0 + \sum_{i=L,M,K} \alpha_i \ln P_i + \frac{1}{2} \sum_{i=L,M,K} \sum_{j=L,M,K} \beta_{ij} \ln P_i \ln P_j \\ + \gamma \ln Y_1 + \frac{1}{2} \delta \ln Y_1^2 + \sum_{i=L,M,K} \rho_i \ln P_i \ln Y_1 + \sigma D \end{aligned} \quad (7)$$

The operating area of JR Shikoku is very small compared to those of JR Hokkaido and JR Kyushu, and the railway network has not been sufficiently developed. Accordingly, we adopt the dummy variable (D=1) for the constant term of JR Shikoku. From Shepherd's lemma, the share equations of inputs (i=L,M,K) are obtained as follows:

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[10] Since the sum of three share equations must be one, one of them can be dropped.

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial C}{\partial P_i}\frac{P_i}{C} = \frac{P_i X_i}{C} = \alpha_i + \sum_{j=L,M,K} \beta_{ij} \ln P_i + \rho \ln Y_1 . \qquad (8)$$

We can now estimate the simultaneous equations in the same way as the previous section's by the maximum likelihood (ML) method.

The results of the estimations

This section will show the results of the estimations. Tables 2 and 3 display the results of the estimations of the cost functions of the main-island JRs and the three-island JRs respectively. The standard errors are parenthetically represented, and the results are quite good.

< Tables 2 and 3>

The test of the economies of scale and scope

This section will move on to verify the economies of scale and scope, based on the results of the estimations.

The definitions of the economies of scale and scope

First, the product-specific economies of scale are originally defined as follows:

$$[\partial C(Y_1, Y_2)/ \partial Y_1] \times [Y_1 / (C(Y_1, Y_2) - C(0, Y_2))]$$

$$[\partial C(Y_1, Y_2)/ \partial Y_2] \times [Y_2 / (C(Y_1, Y_2) - C(Y_1, 0))]. \qquad (9)$$

If these figures are lower (higher) than 1, the product-specific economies (diseconomies) of scale exist. However, as previously stated in this paper, since the translog functional form does not admit $C(0, Y_2)$ and $C(Y_1, 0)$, the economies of scale cannot be verified directly[11]. At this moment, the following indices shall be used:

$$SCALE(Y_1) \equiv \partial \ln C(Y_1, Y_2)/ \partial \ln Y_1$$

$$SCALE(Y_2) \equiv \partial \ln C(Y_1, Y_2)/ \partial \ln Y_2. \quad (10)$$

In the cases of $SCALE(Y_1)<1(>1)$ and $SCALE(Y_2)<1(>1)$, it can be said that the product-specific economies (diseconomies) of scale exist[12].

Second, the economies of scope are originally defined as follows:

$$[C(Y_1, 0)+ C(0, Y_2)-C(Y_1, Y_2)]/ C(Y_1, Y_2) . \quad (11)$$

If this figure is positive (negative), the economies (diseconomies) of scope exist. However, since the translog functional form does not admit $C(0, Y_2)$ and $C(Y_1, 0)$, the economies of scope cannot be verified directly. At this moment, the following index, which is called the weak complementarities of cost, shall be used:

$$SCOPE \equiv \partial^2 C(Y_1,Y_2)/(\partial Y_1 \partial Y_2). \quad (12)$$

In the case of $SCOPE<0(>0)$, the weak complementarities of cost exist (do not exist). This nature of cost is a sufficient condition for the existence of the economies of scope.

The result of the test of the economies of scale and scope

To begin with, we will investigate the economies of scale of the main-island JRs.

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[11] See Baumol, Panzar and Willig (1982) concerning the further discussions of economies of scale and scope.

[12] Note $\partial \ln C(Y_1, Y_2)/ \partial \ln Y_k =[\partial C(Y_1, Y_2)/ \partial Y_k]\times [Y_k /C(Y_1, Y_2)]$.

Table 4 shows the result of the test. First, the economies of scale exist in the incumbent railway service in that SCALE(Y_1)<1 holds for JR East and JR West after the privatization[13]. Second, the economies of scale exist in the Shinkansen service because SCALE(Y_2)<1 holds for all JR East, JR Central, and JR West after the privatization. The result of the test is reliable because the entire estimates are statistically significant at the 5% level. It can be concluded from what has been stated that the main-island JRs have the economies of scale in both the incumbent railway service and the Shinkansen service.

<Table 4>

Next, we will investigate the economies of scope of the main-island JRs, as shown in Table 4. The economies of scope appear to exist in that SCOPE<0 holds for JR East and JR West after the privatization. However, these figures are quite small in comparison with these standard errors. At this moment, we shall carry out Wald test concerning the null hypotheses that the given set of parameters is jointly zero. It follows that the values of χ^2 are 0.357 (the p-value is 0.550) and 1.302 (the p-value is 0.254) respectively, and therefore we cannot reject the null hypotheses. To sum up, we do not have conclusive evidence to show that JR East and JR West have the economies of scope. On the other hand, the negative figure of SCOPE of JR Central is large, and the value of χ^2 is 12.813 (the p-value is 0.000). We can safely say that JR Central has

[13] The value of JR Central is negative because the monotonicity condition with regard to the output of the incumbent railway service is not satisfied. This is probably because the output of the incumbent railway service of JR Central is so small that the estimated model is not proper around this area. However, it should be noted that such an anomaly is not observed in other samples.

the economies of scope. The question of why only JR Central has the economies of scope will arise. The possible reason is that JR Central is a special company which is operating a very large part of the Shinkansen service but which is operating a small part of the incumbent railway service, and it has not been able to make good use of the scope economies. In conclusion, the main-island JRs except for JR Central cannot be said to have the economies of scope.

Finally, we will refer to the economies of scale of the three-island JRs. Table 5 shows the result of the test. The economies of scale exist in the incumbent railway service in that $SCALE(Y_1)<1$ holds for JR Hokkaido, JR Shikoku, and JR Kyushu after the privatization. The result of the test is reliable because the entire estimates are statistically significant at the 5% level.

< Table 5>

To sum up, on one hand, there are the economies of scale in both the incumbent railway service and the Shinkansen service, which presumably leads to the different costs in each region. On the other hand, since there is no conclusive proof to show that the economies of scope exist, we cannot be absolutely certain that the additional provision of the Shinkansen service would decrease the cost for providing the incumbent railway service.

The regional gap of cost between the six JRs

In this section, based on the results of the estimation, the long-term marginal costs of each output, $\partial C(L, M, K, Y_1, Y_2)/\partial Y_i$, will be calculated to compare the six JRs. First, the upper row of Table 6 shows the long-term marginal costs of the incumbent railway service of five JRs, excluding JR Central, in which the reliable estimate cannot be obtained. The marginal costs of the incumbent railway service of JR East and JR West, which own Shinkansen, are both about 6 yen. On the other hand, those of JR Hokkaido, JR Shikoku and JR Kyushu, which do not own Shinkansen, are considerably different. The marginal cost of JR Shikoku is very high (about 11 yen) while that of JR Kyushu is very low (about 5 yen, which is in fact lower than the figures of JR East and JR West). At any rate, we can see that there is a large regional gap in the incumbent service because of the different scales between the six JRs at the time of privatization. However, it will be noteworthy that JR East, which is by far and away the largest company in the incumbent service, is not necessarily operating at the least cost level. One reason for this is that JR East has to cover the low-demand areas such as Tohoku and Hokuriku as well as the Tokyo metropolitan area. Another reason is probably that the economies of scope are not strong when the incumbent railway and the Shinkansen services are compared. In addition, our new observation is that the cost gap is large within the three-island JRs. This means that we cannot discuss their management problems in the same way because they are so different.

Next, the lower row of Table 6 shows the long-term marginal costs of the Shinkansen service of the main-island JRs. Although the marginal costs of the Shinkansen service of JR East and JR West are similar, about 16 yen and 14 yen respectively, it is interesting to note that JR West, which owns the higher-demand Sanyo-Shinkansen, is operating at the lower cost level than JR East, which owns the lower-demand Tohoku, Joetsu, and Nagano Shinkansen. More noteworthy is the fact that the marginal cost of the Shinkansen service of JR Central, which connects the three metropolises of Tokyo, Nagoya, and Osaka, is very low (about 9 yen), as compared with those of JR East and JR West. This means that there is a large cost gap of the Shinkansen service between high-demand and low-demand areas so that we cannot make a valid comparison of the management problems of the Shinkansen service across different areas. Although it is now planned to construct further Shinkansen lines even in the low-demand areas, it is a matter of concern that there will be financial difficulties.

Conclusion

This paper has examined the cost structure of the six passenger JRs after the privatization. As a result, we have found that the economies of scale exist while the economies of scope do not always exist. Furthermore, as expected, there are regional gaps not only between the main-island and the three-island JRs but also within them. Thus, we have empirically observed the regional gap of the JR group after the privatization. Some problems have been left unanswered. First, this paper focused on the aspect of cost structure. We need to take account of the aspect of demand and revenue. Furthermore, we should consider the competition of the JR group against other railway companies. Finally, the competition between railway, motorcar, and airplane must be taken into consideration. We are fully aware of the questions stated above and consider them to be subjects for future research.

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Table 1 The annual outputs of six JRs after the privatization (1987-1999)

	Hokkaido	East	Central	West	Shikoku	Kyushu	Average
Incumbent railway	4595.23	107034.49	9597.85	37572.31	1968.69	8277.92	28174.42
Shinkansen	--	15604.58	39172.23	14904.46	--	--	23227.09

Note. output: 10^6 passenger-km

Table 2 The result of the estimation of the main-island JRs

Coefficient	α_0	α_l	α_m	β_{lk}	β_{mk}	β_{lm}	γ_1	γ_2
Estimate	0.43788	0.39342	0.04872	-0.14210	-0.00621	-0.01253	0.37485	2.34822
Standard error	0.13783 **	0.01279 **	0.00143 **	0.01807 **	0.00266 **	0.00252 **	0.04653 **	0.59627 **

Coefficient	δ_{11}	δ_{12}	δ_{22}	ρ_{1m}	ρ_{1k}	ρ_{2m}	ρ_{2k}	σ_2
Estimate	0.26288	-0.24639	4.81855	-0.01347	0.04773	-0.04949	0.43178	-4.55319
Standard error	0.07000 **	0.11789 **	1.27700 **	0.00168 **	0.01657 **	0.00422 **	0.03717 **	1.21306 **

Note 1. the cost function R^2=.945118/the labor share R^2=.873700/the material R^2=.926644

Note 2. **statistical significance at the 5% level, *statistical significance at the 10% level

Table 3 The result of the estimation of the three-island JRs

Coefficient	α_0	α_l	α_m	β_{lk}	β_{mk}	β_{lm}
Estimate	0.18317	0.63252	0.08998	-0.18497	-0.01302	-0.00992
Standard error	0.01603 **	0.00543 **	0.00090 **	0.00930 **	0.00155 **	0.00126 **
Coefficient	γ_1	δ_{11}	ρ_{1m}	ρ_{1k}	σ	
Estimate	0.40305	-0.16474	0.01089	-0.03533	-0.60799	
Standard error	0.03671 **	0.10607	0.00150 **	0.00960 **	0.07028 **	

Note 1. the cost function R^2=.972576/the labor share R^2=.776247/the raw material R^2=.873613

Note 2. **statistical significance at the 5% level, *statistical significance at the 10% level

Table 4 The economies of scale and scope of the main-island JRs

	East	Central	West
Scale economies of Incumbent railway	0.66233	--	0.41007
Standard error	0.04094 **	--	0.03066 **
Scale economies of Shinkansen	0.23876	0.64858	0.37637
Standard error	0.09949 **	0.11276 **	0.09518 **
Scope economies	-0.08826	-0.37531	-0.09205
Standard error	0.14766	0.10485 **	0.08066

Note. **statistical significance at the 5% level, *statistical significance at the 10% level

Table 5 The economies of scale of the three-island JRs

	Hokkaido	Shikoku	Kyushu
Scale economies of Incumbent railway	0.41692	0.55385	0.31610
Standard error	0.06369 **	0.23147 **	0.06497 **

Note. **statistical significance at the 5% level, *statistical significance at the 10% level

Table 6 The long-term marginal costs of the six JRs (1987-1999)

	Hokkaido	East	Central	West	Shikoku	Kyushu
Incumbent railway	8.86155	6.39085	--	6.09813	10.9744	4.96706
Shinkansen	--	15.8018	9.31358	14.1091	--	--

Note. unit: yen /passenger-km

Figure 1 The six passenger JRs